
# Using duck proxies and surface water to inform hunting arrangements for 2023

compiled by Marcel Klaassen

Surface water data:
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Victorian Duck Season Priority Waterbird Counts:
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# Contents

# 1 Introduction

Based on literature, practices elsewhere, and earlier recommendations, duck harvest management for Victoria should contain indices that inform on (i) breeding conditions in Victoria, (ii) breeding conditions throughout SE Australia, (iii) current or recent duck population size in Victoria, and (iv) duck population size throughout SE Australia.

In the protocol outlined in *Relationships among duck population indices and abiotic drivers to guide annual duck harvest management* by Klaassen and Kingsford (2021) we proposed to calculate five indices reflecting the above elements i-iv. Three of these indices, reflecting breeding condition elements i and ii, use availability of water in the landscape (LANDSAT satellite imagery) across up to 4 regions in SE Australia and up to three years back in time. The models underlying these three indices are updated annually making use of the latest LANDSAT and game count data. The three indices used in the models are based on the *Victorian Duck Season Priority Waterbird Counts* (from here on Priority Game Counts or PGC), the *Eastern Australian Waterbird Survey counts for Victoria* (Victoria aerial counts or VicC) and the *Eastern Australian Waterbird Survey counts for NSW* (NSW aerial counts or NSWC).

While the first three indices are based on the availability of water in the landscape in SE Australia over the past three years, the two remaining indices are directly calculated from the 2022 VicC and NSWC data.

After starting with presenting the water and count data in section 2, the updated models for the first three indices are presented in section 3. Next, in section 4, we present all five indices and compare these with actual hunting regulation data over the years 1991 to 2021 and briefly evaluate their use in advising on future annual hunting arrangement.

Finally, in section 5, a proposed hunting arrangement for 2023 is presented, which suggests to implement a bag limit of four ducks per day.

# 2 The data

## 2.1 Water surface area across SE Australia

The monthly maximum water surface area in the landscape calculated from LANDSAT imagery using the DEA Sandbox tool were kindly obtained and shared by Roxane Francis and Richard Kingsford (UNSW) for the following regions:

- Lake Eyre Basin catchment (LEB)
- Murray-Darling Basin catchment (MDB)
- SE Australia south of the MDB (SEDB)
- Victoria (VIC)


Figure 1: The regions across which percentage of surface water was extracted from satellite imagery

In Figure 2, the water surface area (in %) across Victoria (VIC), Murray-Darling Basin (MDB), SE Australia south of the MDB (SEDB) and Lake Eyre Basin (LEB) is depicted. The monthly values are plotted in blue with the last three year's data plotted in red. It is these last three years of data on which the graph also zooms in, since it is this period of water availability in the landscape that is used in making predictions on duck numbers and calculation of three of the five indices. The right-aligned, 12-month rolling average for the water surface areas (i.e. annual trends in water surface area corrected for monthly variations) are depicted in green.

The interim harvest model is a statistical model. This means that count and water data over the past three decades is being used to make models and that these models are next used to make predictions on waterfowl numbers using the latest water data. Such use of models to make predictions is only allowed when the input values are not extremely outside the range of values used to make the predictive model. While we have experienced an unprecedented third La Nina year in a row, Figure 2 shows that the current amounts of water in the landscape across most of the four regions are high but not abnormal. This supports the modelling approach taken.


Figure 2: Percentage water surface area over time for four Australian regions considered to be of importance to duck numbers in Victoria

## 2.2 Waterfowl across SE Australia

As mentioned earlier the analyses here presented rely both on water surface data presented above and on three sets of waterfowl counts:

- The Victorian Duck Season Priority Waterbird Counts (PGC; e.g. 2021 report), the latest available information of which was made available to the analyses presented here by Peter Menkhorst (Arthur Rylah Institute for Environmental Research). These counts mostly take place a month before the duck hunting season during the month of February.
- the Victorian aerial counts (VicC) were extracted from the Eastern Australian Waterbird Survey data (EAWS; Kingsford, R. T., J. L. Porter, K. J. Brandis, and S. Ryall. 2020. Aerial surveys of waterbirds in Australia. Scientific Data 7:1-6.), with the latest updates made available for the analyses by John Porter and Richard Kingsford (UNSW). These counts typically take place in October each year. From this data set we used bands 1-3 to represent Victoria (and the SE of SA)
- The NSW aerial counts (NSWC) were extracted from the same EAWS data set as bands 4-6 covering NSW and southern Queensland as well as the E of SA bordering NSW.

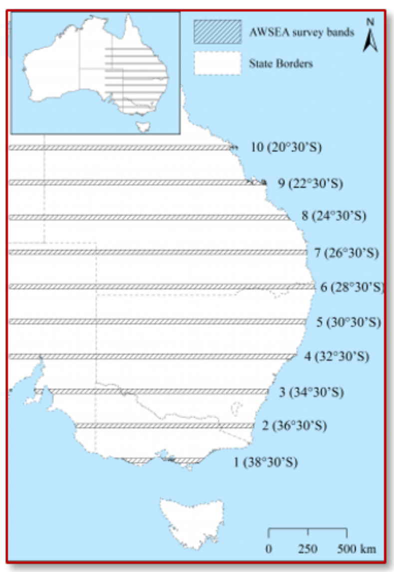


Figure 3: EAWS survey bands across the east of Australia

In Figure 4 below, an overview of the count data used in the modelling and starting 1991 is presented. Also presented in this figure are the bag limits set over the period 1991-2021. Note that the three count data sets show relatively low levels for 2022.

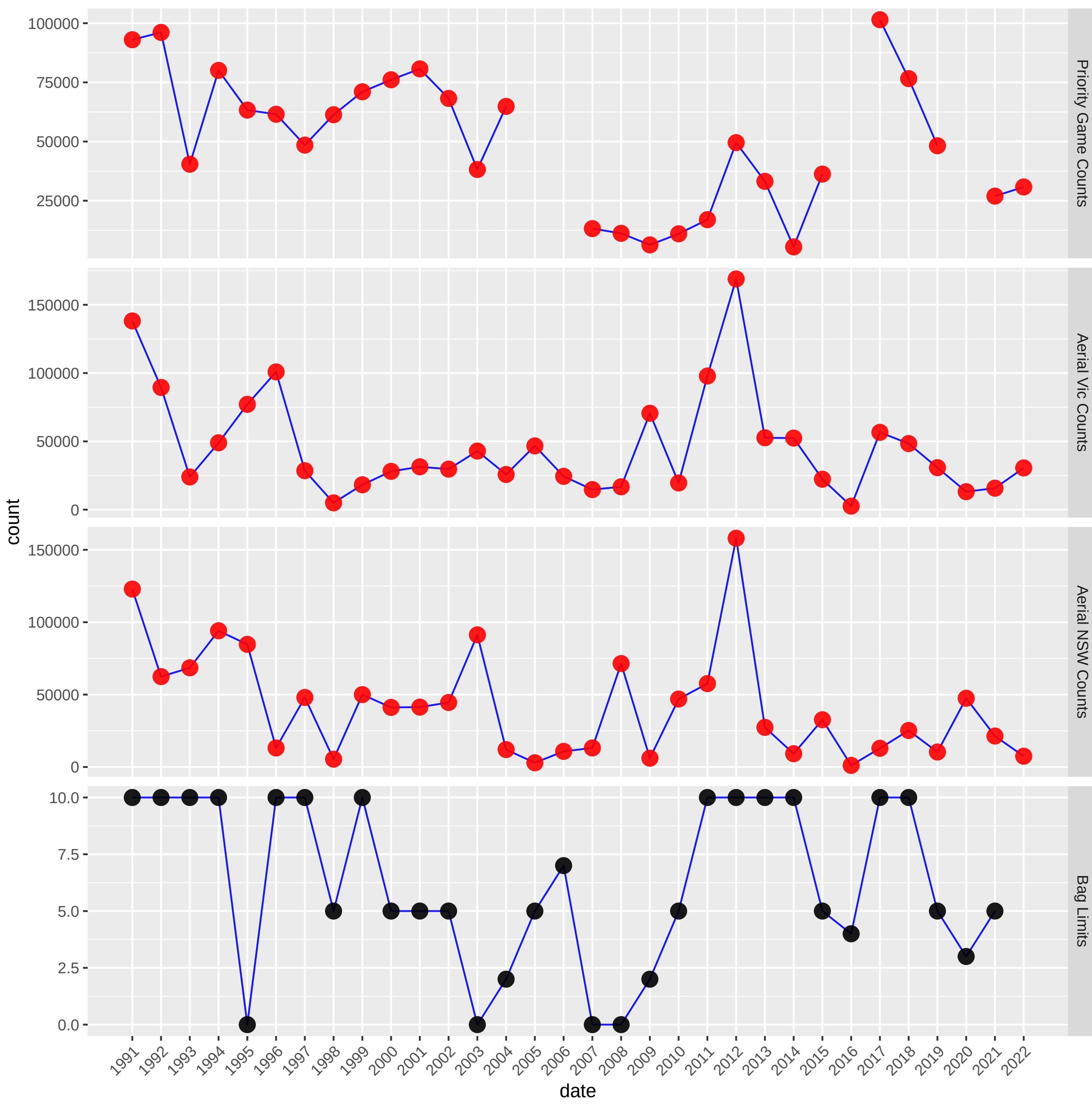


Figure 4: Overview of all the count data used in the modelling as well as the bag limits that have been imposed up till 2021, i.e. until the moment the interim harvest model came into effect.

# 3 The models and thresholds

## 3.1 Predictive models for priority game counts

We used linear modelling to conduct a regression across all priority game count data across 40 priority wetlands for the years in which also water surface data was available for all four regions. Water surface area was time shifted by 4 months. This was done to allow already predicting in December what the expected duck numbers are going to be in March the following year, from which sensible hunting arrangements can next be gauged.

We ran models using as explanatory variables the average water surface area over the preceding 12 months for all four regions (designated by the respective region codes LEB, MDB, SEMD and VIC). For all four regions, we also used the average water surface area over the period 13-36 months (i.e. 2 years of water data) prior to the "decision" point in December (designated by LEB2, MDB2, SEMD2 and VIC2). All possible combinations of these 8 explanatory *water surface* variables were tested.

We first present a correlation chart (Fig. 5) for all variables used in the models, including their Pearson correlation coefficients. Next, in Table 1, we present the 25 best models ranked by their deltaAIC value, starting with the best model (deltaAIC=0). Typical models with a deltaAIC between 0 and 2 are considered models with substantial statistical support and models with a score between 2 and 7 to have moderate statistical support only.

In Table 1, the use of a red font indicates models where all explanatory variables have a P<0.05. The orange columns indicate variables where we a priori expected a possible effect.

We ultimately selected a model as the most satisfying model that:

1. was high ranking
2. had significant and preferably positive parameter estimates for all its parameters (not considering the intercept)
3. had a high adjR2 or R-squared

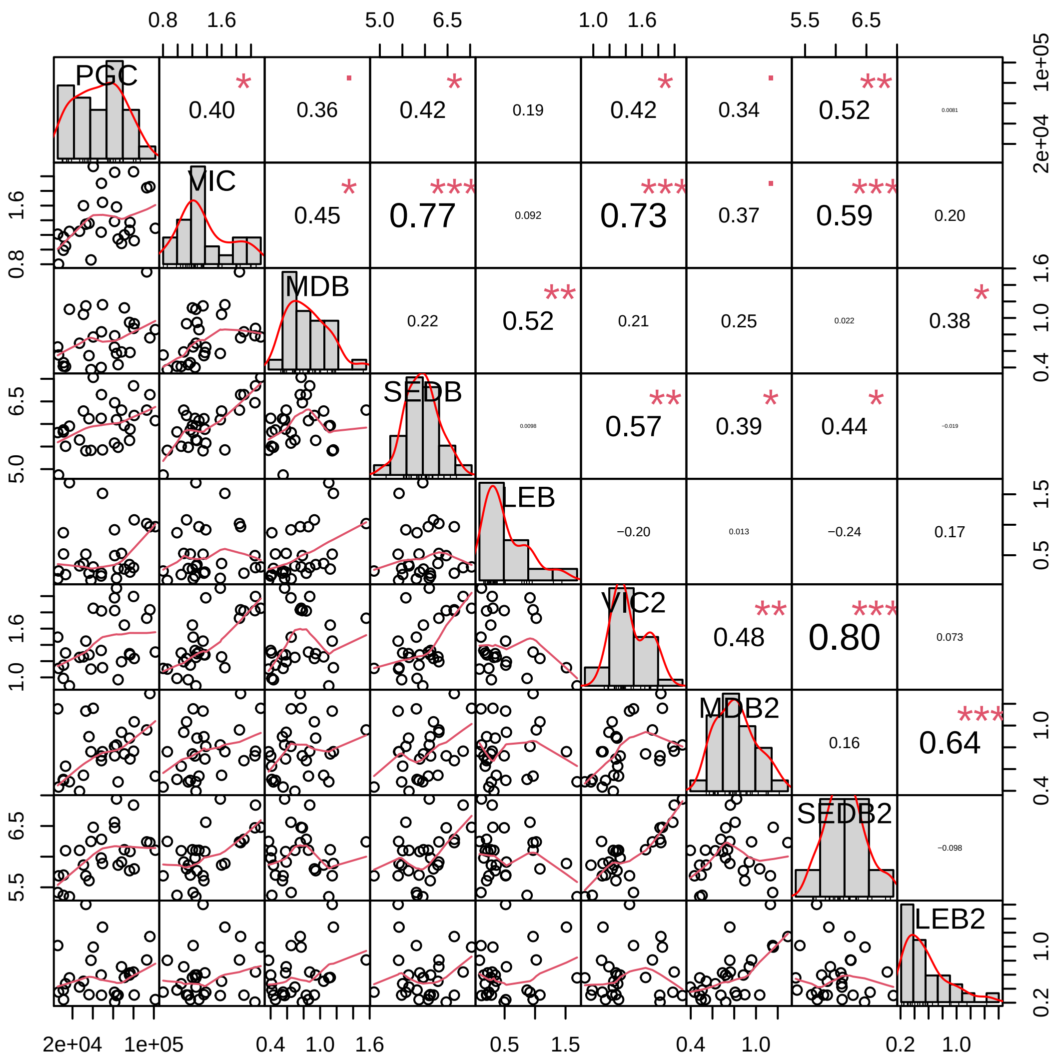


Figure 5: Correlation chart depicting the correlations between the annual game counts (PGC) and all eight explanatory water surface variables used in the models, with frequency distributions of the variables depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix. Stars indicate significance levels.

Table 1: Top 25 models predicting game counts in Victorian priority wetlands ranked starting with best best (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero.

| (Intercept) | LEB | LEB2 | MDB | MDB2 | SEDB | SEDB2 | VIC | VIC2 | adjR^2 | delta | AllSignif |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -363395 | NA | -44356 | 51390 | 93891 | NA | 71185 | NA | -70027 | 0.614 | 0.00 | TRUE |
| -193794 | NA | NA | 34643 | NA | NA | 36174 | NA | NA | 0.390 | 2.96 | TRUE |
| -364725 | 8099 | -43191 | 43990 | 92054 | NA | 70719 | NA | -65687 | 0.624 | 3.30 | FALSE |
| -217972 | 22409 | NA | NA | NA | NA | 42575 | NA | NA | 0.373 | 3.75 | TRUE |
| -374409 | NA | -42734 | 50374 | 91135 | 2966 | 70587 | NA | -70880 | 0.616 | 3.87 | FALSE |
| -363599 | NA | -44320 | 51523 | 93856 | NA | 71234 | -349.3 | -69818 | 0.614 | 3.98 | FALSE |
| -221747 | 21529 | NA | NA | 28856 | NA | 39614 | NA | NA | 0.430 | 4.04 | FALSE |
| -328858 | NA | NA | 36114 | 43868 | NA | 63793 | NA | -46476 | 0.486 | 4.45 | FALSE |
| -195022 | NA | NA | 30166 | 21493 | NA | 34212 | NA | NA | 0.420 | 4.54 | FALSE |
| -173213 | NA | -29066 | 38202 | 46842 | NA | 29232 | NA | NA | 0.483 | 4.62 | FALSE |
| -214818 | 13218 | NA | 24429 | NA | NA | 39787 | NA | NA | 0.417 | 4.71 | FALSE |
| -217327 | NA | NA | 31349 | NA | 9382 | 31183 | NA | NA | 0.410 | 5.03 | FALSE |
| -348793 | NA | NA | 47671 | NA | 25879 | 44017 | -40750.9 | NA | 0.473 | 5.14 | FALSE |
| -246146 | 20767 | NA | NA | NA | 11540 | 35942 | NA | NA | 0.404 | 5.32 | FALSE |
| -205695 | 23575 | -22166 | NA | 49900 | NA | 36286 | NA | NA | 0.469 | 5.33 | FALSE |
| -240335 | NA | NA | 38368 | NA | NA | 47278 | NA | -16318 | 0.402 | 5.39 | FALSE |
| -170871 | NA | NA | NA | NA | NA | 36725 | NA | NA | 0.266 | 5.41 | TRUE |
| -176889 | NA | NA | NA | 30868 | NA | 33804 | NA | NA | 0.332 | 5.51 | FALSE |
| -187742 | NA | -7564 | 38108 | NA | NA | 35481 | NA | NA | 0.397 | 5.62 | FALSE |
| -214433 | NA | NA | 39710 | NA | NA | 41125 | -9335.9 | NA | 0.397 | 5.65 | FALSE |
| -304300 | 20967 | NA | NA | 44478 | NA | 58425 | NA | -29872 | 0.459 | 5.88 | FALSE |
| -314143 | 23391 | -28518 | NA | 77324 | NA | 61092 | NA | -40908 | 0.520 | 6.15 | FALSE |
| -218735 | 14826 | NA | 18226 | 23818 | NA | 38051 | NA | NA | 0.453 | 6.18 | FALSE |
| -209773 | NA | NA | NA | NA | 14194 | 29094 | NA | NA | 0.314 | 6.27 | FALSE |
| -196605 | 14443 | -28678 | 26462 | 48769 | NA | 33039 | NA | NA | 0.514 | 6.49 | FALSE |

## 3.2 Predicted versus observed PGC and threshold calculation

Based on the criteria listed above we select model 2 as the preferred model. Below we present the critical statistics for this model and a plot of the predicted versus the observed Victorian Game counts. In this graph (Fig. 6), the symbol colour reflects hunting bag limits for the season (not considering potential separate limitations for individual species and special restrictions during opening weekend). Red line depicts *observed=predicted*, while the blue line is the linear regression relationship with grey shading reflecting the 95% confidence interval of this line. Black horizontal line is the threshold for the dependent variable, reflecting the lower limit above which unlimited seasons were called. The black square symbol resembles data for 2022. Since hunting bag limits were based on this methodology starting with the 2022 hunting season, the hunting bag limit for 2022 was discarded in calculating the threshold.

Game counts in 2022 turned out lower than average and came out at 30799 or on the 28.6 percentile of all counts.

As expected, since adding a single year to the existing data set of 27 years is unlikely to change the outcome by much, the current model is very similar to the model calculated last year and reported in Using duck proxies and surface water to inform hunting arrangements (Klaassen & Kingsford 2021). Accordingly, the threshold value for the Victorian Game counts increased only slightly from 74,700 to 77,000. This threshold value was calculated by taking the highest predicted PGC amongst years in which hunting restrictions were in place (i.e. the bag limit was less than 10; all non-purple symbols in Fig. 6).

| | |
|---|---|
| Observations | 28 |
| Dependent variable | PGC |
| Type | OLS linear regression |

| | |
|---|---|
| F(2,25) | 8.01 |
| $R^2$ | 0.39 |
| Adj. $R^2$ | 0.34 |

| | Est. | S.E. | t val. | p |
|---|---|---|---|---|
| (Intercept) | -193794.33 | 67856.97 | -2.86 | 0.01 |
| MDB | 34643.35 | 15357.86 | 2.26 | 0.03 |
| SEDB2 | 36174.18 | 11115.41 | 3.25 | 0.00 |

Standard errors: OLS

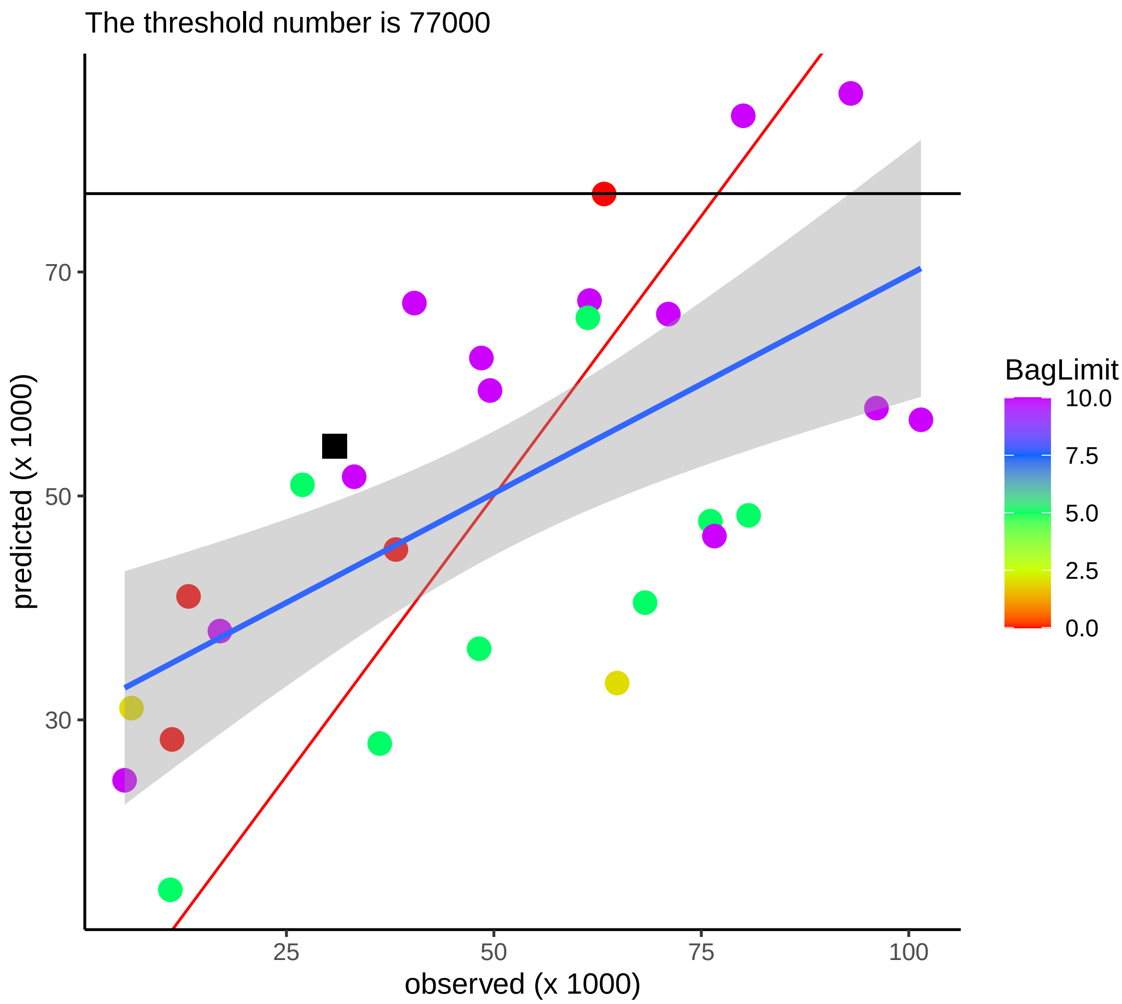


Figure 6: Predicted versus observed Victorian Game counts, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2022. Red line is observed=predicted and blue line is the linear regression relationship (with 95% confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

## 3.3 Predictive models for aerial Victorian counts

We ran models analogous to what we presented above for the "Water surface areas and game counts in priority wetlands". Also the selection of the preferred model followed the same selection criteria. We again present a correlation chart (Fig. 7) for all variables used in the models, including their Pearson correlation coefficients as well as a table (Table 2) presenting the 25 best models, starting with the best model (deltaAIC=0).

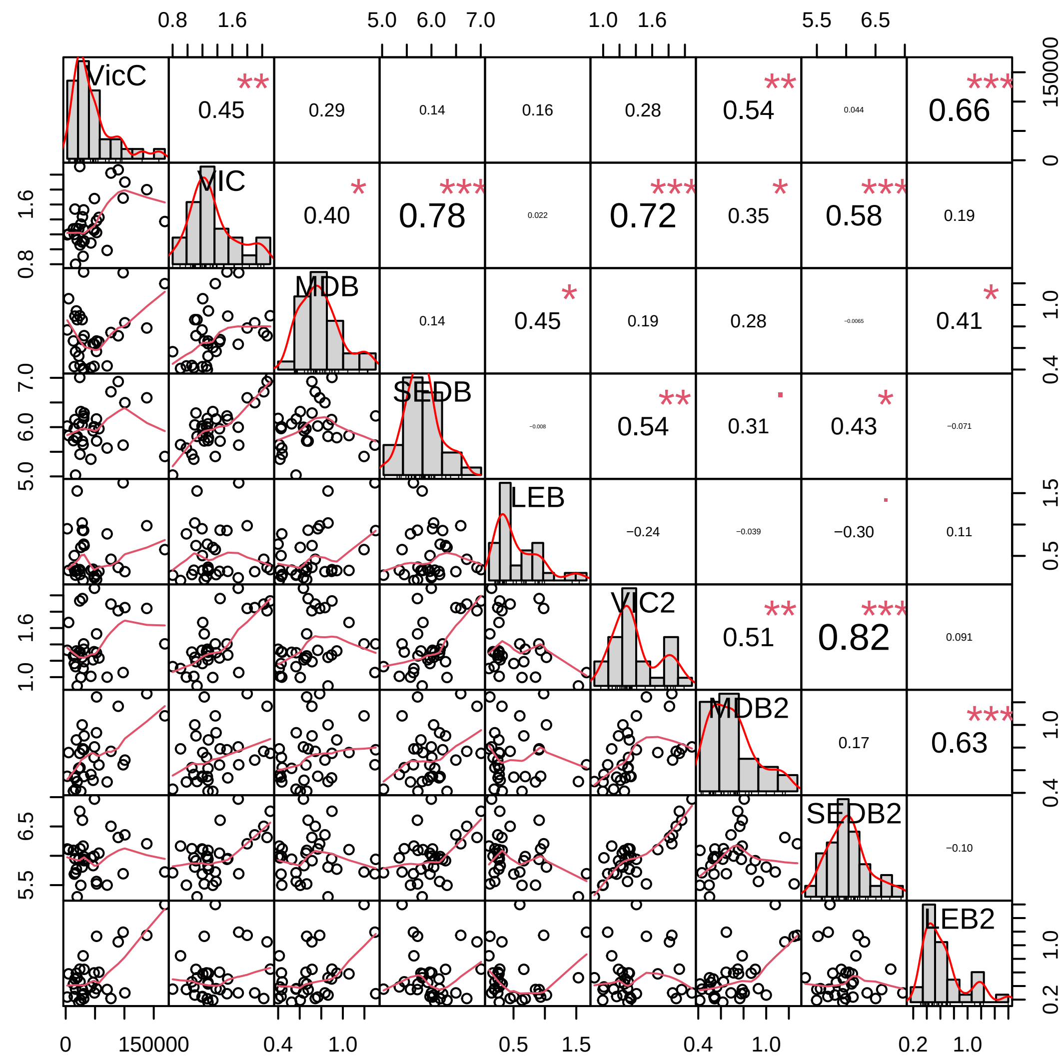


Figure 7: Correlation chart depicting the correlations between the annual EAWScounts for Victoria (VicC) and all eight explanatory water surface variables used in the models, with frequency distributions of the variables depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix.

Table 2: Top 25 models predicting annual EAWS counts for Victoria ranked starting with best best (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero.

| (Intercept) | LEB | LEB2 | MDB | MDB2 | SEDB | SEDB2 | VIC | VIC2 | adjR^2 | delta | AllSignif |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -42863 | NA | 65684 | NA | NA | NA | NA | 39042 | NA | 0.549 | 0.00 | TRUE |
| 54168 | NA | 59496 | NA | NA | -20972 | NA | 62343 | NA | 0.569 | 1.39 | FALSE |
| 35419 | NA | 62076 | NA | NA | NA | -15198 | 49748 | NA | 0.563 | 1.83 | FALSE |
| -38176 | NA | 70392 | -19165 | NA | NA | NA | 43838 | NA | 0.561 | 2.00 | FALSE |
| -46778 | 8767 | 64576 | NA | NA | NA | NA | 39028 | NA | 0.558 | 2.23 | FALSE |
| -46572 | NA | 60625 | NA | 12909 | NA | NA | 36868 | NA | 0.553 | 2.58 | FALSE |
| -40683 | NA | 65442 | NA | NA | NA | NA | 42691 | -5091 | 0.550 | 2.76 | FALSE |
| 168252 | NA | 53937 | NA | NA | -24654 | -18842 | 79706 | NA | 0.590 | 2.88 | FALSE |
| 78775 | NA | 64448 | -24960 | NA | -24971 | NA | 73031 | NA | 0.588 | 3.02 | FALSE |
| 211420 | NA | NA | NA | 95331 | -55369 | NA | 124954 | -53782 | 0.587 | 3.06 | TRUE |
| -42209 | 17557 | 71997 | -34730 | NA | NA | NA | 47703 | NA | 0.587 | 3.10 | FALSE |
| 80313 | NA | 46039 | NA | 28741 | -28408 | NA | 65762 | NA | 0.584 | 3.32 | FALSE |
| 247633 | NA | 58800 | -35434 | NA | -31765 | -26183 | 101643 | NA | 0.624 | 3.37 | FALSE |
| 65425 | NA | 67345 | -25892 | NA | NA | -19794 | 59464 | NA | 0.583 | 3.42 | FALSE |
| 87494 | 19611 | 65569 | -43001 | NA | -27795 | NA | 80649 | NA | 0.620 | 3.73 | FALSE |
| 50129 | 8737 | 58401 | NA | NA | -20942 | NA | 62296 | NA | 0.577 | 3.82 | FALSE |
| 360762 | NA | NA | NA | 71698 | -53327 | -33761 | 112794 | NA | 0.577 | 3.83 | TRUE |
| -28132 | NA | 70667 | NA | NA | NA | NA | NA | 26079 | 0.487 | 4.12 | FALSE |
| 233926 | NA | 34313 | NA | 38745 | -35659 | -23868 | 88946 | NA | 0.615 | 4.14 | FALSE |
| 60634 | NA | 58930 | NA | NA | -21659 | NA | 68605 | -7672 | 0.571 | 4.29 | FALSE |
| 259105 | NA | NA | -29894 | 104639 | -63788 | NA | 146891 | -62871 | 0.613 | 4.30 | FALSE |
| 323377 | NA | 37893 | -37572 | 41860 | -44084 | -32056 | 112950 | NA | 0.654 | 4.35 | FALSE |
| 6825 | NA | 72869 | NA | NA | NA | NA | NA | NA | 0.439 | 4.38 | TRUE |
| 81910 | NA | 60476 | NA | NA | NA | -25856 | 43198 | 19615 | 0.569 | 4.42 | FALSE |
| 38230 | NA | 55026 | NA | 17080 | NA | -16697 | 47927 | NA | 0.569 | 4.45 | FALSE |

## 3.4 Predicted versus observed VicC and threshold calculation

Based on the criteria set out earlier we select model 1 as the preferred model for which we present the critical statistics below, followed by a plot of the predicted versus the observed EAWS counts for Victoria (Fig. 8).

The EAWS count for Victoria in 2022 was average with a count of game birds amounting to 30557, which was exactly at the 50 percentile of all counts used in the analyses.

Also here, adding a single year to the existing data set of 31 years did not result in a major change to this model compared to the one reported last year (Klaassen & Kingsford 2021). It has led to a slight downward correction of the threshold value from 50,800 to 50,300.

| | |
|---|---|
| Observations | 32 |
| Dependent variable | VicC |
| Type | OLS linear regression |

| | |
|---|---|
| F(2,29) | 17.67 |
| $R^2$ | 0.55 |
| Adj. $R^2$ | 0.52 |

| | Est. | S.E. | t val. | p |
|---|---|---|---|---|
| (Intercept) | -42863.43 | 20596.08 | -2.08 | 0.05 |
| LEB2 | 65683.94 | 13973.45 | 4.70 | 0.00 |
| VIC | 39042.50 | 14653.46 | 2.66 | 0.01 |

Standard errors: OLS

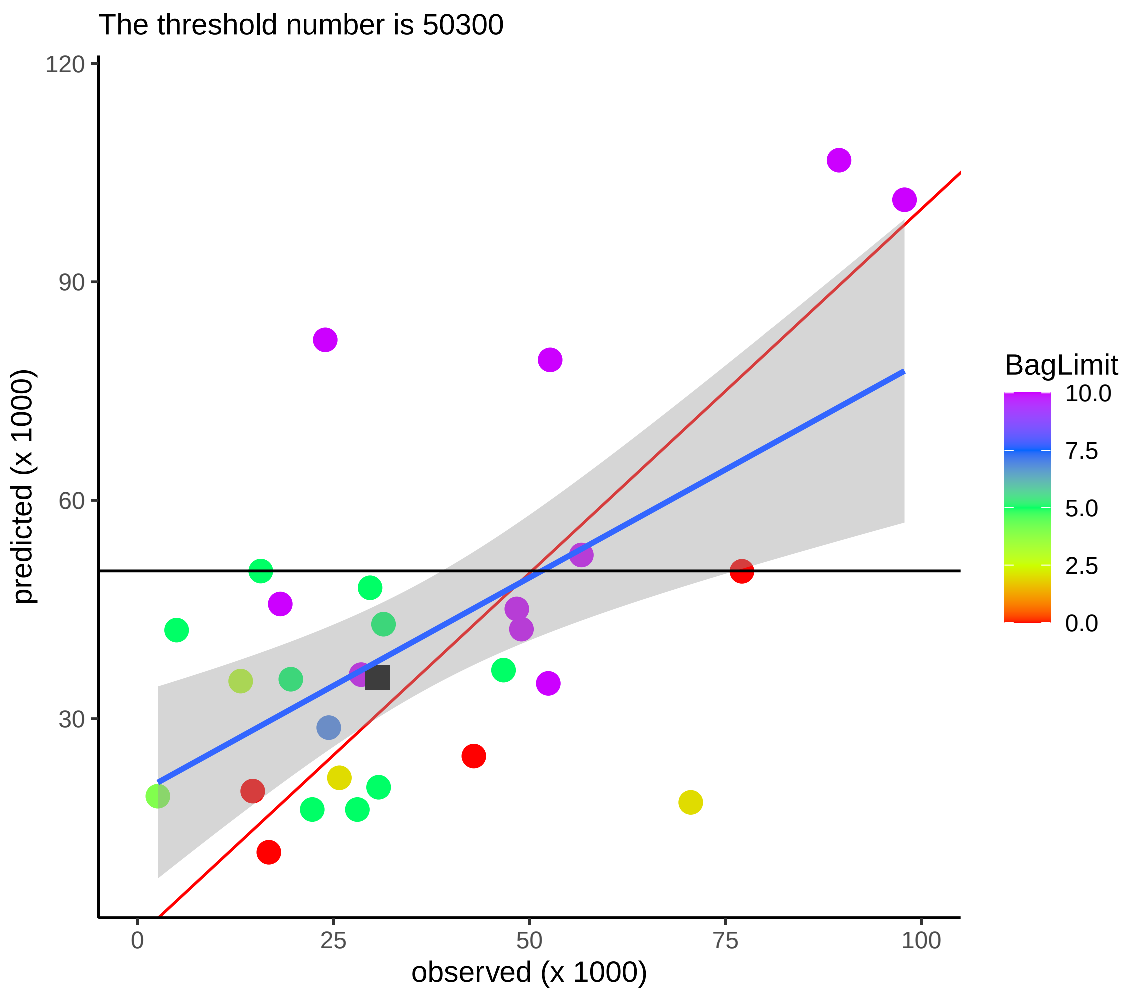


Figure 8: Predicted versus observed EAWS counts for Victoria, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2022. Red line is observed=predicted and blue line is the linear regression relationship (with 95% confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

## 3.5 Predictive models for aerial NSW counts

We again ran a series of models analogous to the above but now to predict annual EAWS counts from NSW from water surface areas across the four regions. The selection of the preferred model again followed the same selection criteria presented earlier. We present a correlation chart (Fig. 9) for all variables used in the models, including their Pearson correlation coefficients as well as a table (Table 3) presenting the 25 best models.

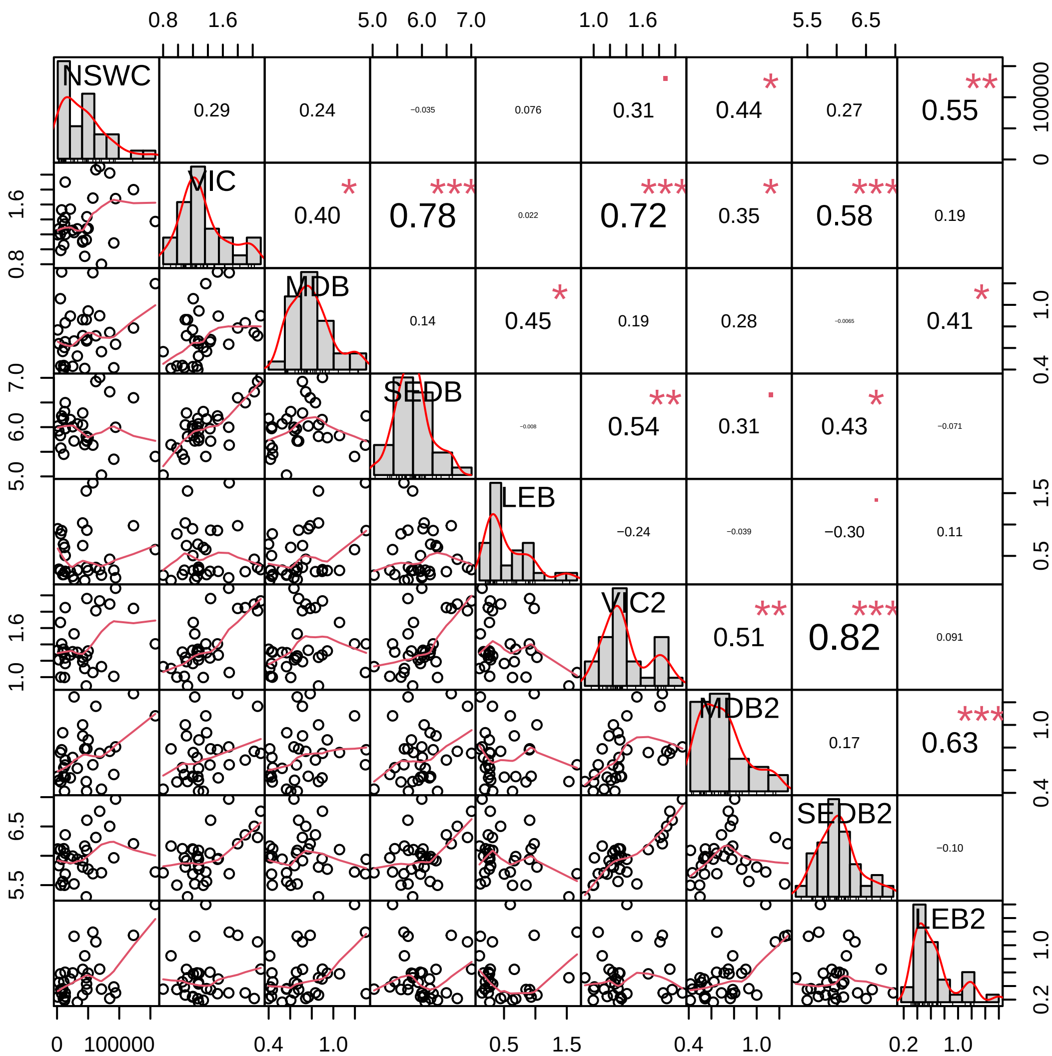


Figure 9: Correlation chart depicting the correlations between the annual EAWScounts for NSW (NSWC) and all eight explanatory water surface variables used in the models, with frequency distributions of the variables depicted on the diagonal and the Pearson correlation coefficients presented in the top right half of the matrix.

Table 3: Top 25 models predicting annual EAWScounts for NSW ranked starting with best best (top row) first. The first nine columns present the estimated intercept and slopes for all eight explanatory water surface variables. NA indicates the variable was absent from the model. The three final columns contain quality indicators of each model: R squared, delta AIC and whether all model slopes were significantly different from zero.

| (Intercept) | LEB | LEB2 | MDB | MDB2 | SEDB | SEDB2 | VIC | VIC2 | adjR^2 | delta | AllSignif |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -187598 | NA | 62908 | NA | NA | NA | 32673 | NA | NA | 0.407 | 0.00 | TRUE |
| -146181 | NA | 62405 | NA | NA | -13757 | 39566 | NA | NA | 0.429 | 1.64 | FALSE |
| -31576 | NA | 56768 | NA | NA | NA | NA | NA | 31005 | 0.372 | 1.82 | FALSE |
| -214016 | 11353 | 61850 | NA | NA | NA | 36200 | NA | NA | 0.420 | 2.10 | FALSE |
| 248083 | NA | NA | NA | 66239 | -60907 | NA | 80558 | NA | 0.414 | 2.46 | TRUE |
| 9985 | NA | 59386 | NA | NA | NA | NA | NA | NA | 0.302 | 2.61 | TRUE |
| -185254 | NA | 60155 | NA | 6277 | NA | 31765 | NA | NA | 0.408 | 2.78 | FALSE |
| -191633 | NA | 63406 | NA | NA | NA | 33774 | -2062 | NA | 0.407 | 2.82 | FALSE |
| -194473 | NA | 63277 | NA | NA | NA | 34314 | NA | -2274 | 0.407 | 2.82 | FALSE |
| -187940 | NA | 62671 | 806.1 | NA | NA | 32655 | NA | NA | 0.407 | 2.82 | FALSE |
| 157218 | NA | 44235 | NA | NA | -37800 | NA | 63725 | NA | 0.404 | 3.01 | FALSE |
| 55010 | NA | 54112 | NA | NA | -17216 | NA | NA | 43992 | 0.401 | 3.15 | FALSE |
| -18521 | NA | 52799 | NA | NA | -32129 | 29025 | 36979 | NA | 0.454 | 3.24 | FALSE |
| -17669 | NA | 55387 | NA | NA | NA | NA | 21729 | NA | 0.337 | 3.58 | FALSE |
| -172465 | 13672 | 61063 | NA | NA | -15594 | 44733 | NA | NA | 0.448 | 3.61 | FALSE |
| -127569 | NA | 52914 | NA | 21351 | -17292 | 38248 | NA | NA | 0.437 | 4.21 | FALSE |
| 195772 | NA | 24390 | NA | 42384 | -48764 | NA | 68767 | NA | 0.437 | 4.23 | FALSE |
| -38724 | 8278 | 55503 | NA | NA | NA | NA | NA | 33568 | 0.380 | 4.28 | FALSE |
| -2747 | NA | 48654 | NA | 25380 | NA | NA | NA | NA | 0.317 | 4.53 | FALSE |
| -104145 | NA | 60405 | NA | NA | -15805 | 32032 | NA | 11863 | 0.431 | 4.54 | FALSE |
| -31012 | NA | 60380 | NA | -9141 | NA | NA | NA | 34005 | 0.374 | 4.58 | FALSE |
| -29687 | NA | 58086 | -4681.2 | NA | NA | NA | NA | 31562 | 0.373 | 4.61 | FALSE |
| 134003 | NA | 46270 | NA | NA | -35332 | NA | 41240 | 27548 | 0.430 | 4.62 | FALSE |
| -146754 | NA | 60746 | 5565.7 | NA | -14352 | 39737 | NA | NA | 0.430 | 4.63 | FALSE |
| -31272 | NA | 56894 | NA | NA | NA | NA | -1032 | 31759 | 0.372 | 4.65 | FALSE |

## 3.6 Predicted versus observed NSWC and threshold calculation

Based on the criteria set out earlier we select model 1 as the preferred model for which we present the critical statistics below, followed by a plot of the predicted versus the observed EAWS counts for Victoria (Fig. 10).

The EAWS count for NSW in 2022 turned out far lower than average and was 7458 or at the 15.6 percentile of all counts.

In this case, adding an additional year to the existing data set of 31 years did result in a change of model compared to the one reported last year (Klaassen & Kingsford 2021). Last year, the preferred model contained explanatory variables MDB2, VIC and SEDB, whereas it now contains LEB2 and SEDB2. However, it should be considered that the correlations between these water surface variables tend to be high (see Fig. 9). This change of model has led to a moderate upward correction of the threshold value from 54,900 to 67,000.

| | |
|---|---|
| Observations | 32 |
| Dependent variable | NSWC |
| Type | OLS linear regression |

| | |
|---|---|
| F(2,29) | 9.96 |
| $R^2$ | 0.41 |
| Adj. $R^2$ | 0.37 |

| | Est. | S.E. | t val. | p |
|---|---|---|---|---|
| (Intercept) | -187597.61 | 87549.15 | -2.14 | 0.04 |
| LEB2 | 62907.88 | 15537.10 | 4.05 | 0.00 |
| SEDB2 | 32673.22 | 14385.50 | 2.27 | 0.03 |

Standard errors: OLS

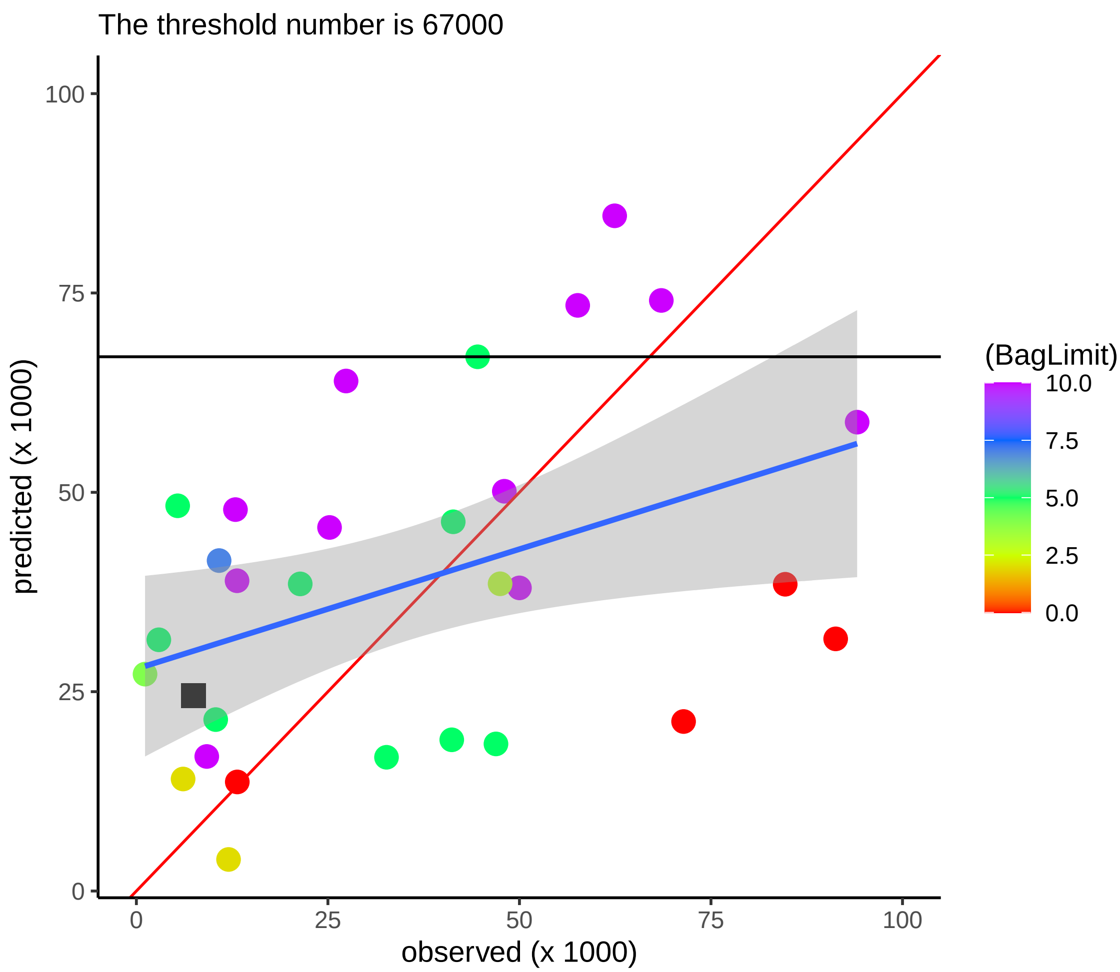


Figure 10: Predicted versus observed EAWS counts for NSW, where symbol colour corresponds with the season's hunting bag limit, and black square is the data for 2022. Red line is observed=predicted and blue line is the linear regression relationship (with 95% confidence interval). The black horizontal line is the threshold or lower limit above which unlimited seasons were called.

# 4 From predictive models to duck population indices

## 4.1 Summary of predictive models

The following preferred models were selected (with R squared in brackets):

PGC ~ SEDB2 + MDB + 1 (0.39)

VicC ~ LEB2 + VIC + 1 (0.55)

NSWC ~ LEB2 + SEDB2 + 1 (0.41)

It should be noted that in all models long-term patterns in water availability (i.e. water in the landscape 2-3 years prior to the counts) appear crucial. Indeed, in the case of NSWC, water in the landscape 12-36 months prior to the counts appeared to be solely responsible for the number of birds counted.

It should moreover be noted that in all cases the birds counted not only depend on the local availability of habitat, but also on conditions elsewhere in SE Australia. Indeed, for PGC the water availability across Victoria as a whole was not in the top model. Similarly, for NSWC water surface area in NSW was also not in the preferred model. Also here, it should again be stressed that water surface areas in the different regions tended to be (highly) correlated (cf. Fig. 3, 6 and 8).

## 4.2 Calculation of the indices

Using the preferred predictive models as well as the two aerial duck counts themselves, following the protocol outlined in *Relationships among duck population indices and abiotic drivers to guide annual duck harvest management* by Klaassen and Kingsford (2021) we calculate indices that broadly inform on the current population status of ducks in SE Australia and Victoria in particular.

Threshold values for game counts in Victoria and aerial surveys for Victoria and NSW were selected above which no years ever had hunting restrictions imposed (and, conversely, below which some years, but not all, had bag limits imposed; see figures 5, 8 and 10 in section 3.2, 3.4 and 3.6, respectively).

The five duck population indices are:

- iPGC: index of game counts limited to 40 priority wetlands using the predictive model from section 3.2 divided by the game count threshold of 77000
- iVicC: index of aerial survey for Victoria using the predictive model from section 3.4 divided by the threshold for these counts of 50300
- iNSWC: index of aerial survey for NSW using the predictive model from section 3.6 divided by the threshold for these counts of 67000
- tfVicC: index of aerial survey for Victoria using actual counts divided by the threshold for these counts of 50300

- **tfNSWC**: index of aerial survey for NSW using actual counts divided by the threshold for these counts of 67000

Index values higher than 1 indicate a good to excellent population status of ducks, while values lower than 1 indicate a poor to good population status.

## 4.3 Past performance of the indices

Below, in Fig. 11, boxplots are presented for the five duck-population indices, as well as the median of these five indices. For all six of these, three box plots are drawn, one for unrestricted hunting seasons (bag limit = 10, blue), one for cancelled hunting season (bag limit = 0, red) and one for hunting seasons with restrictions (bag limit = 2-7, green).

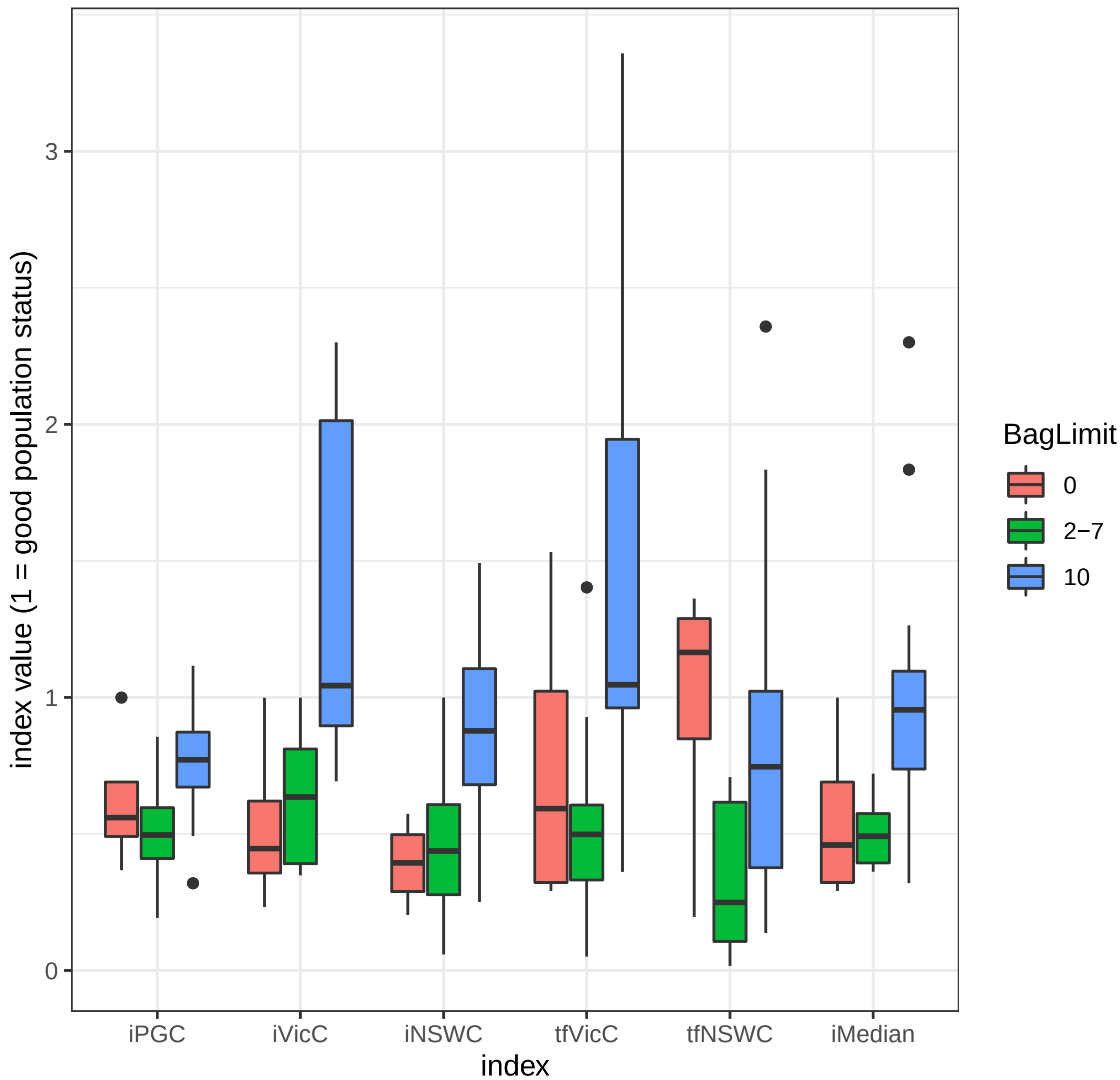


Figure 11: Boxplots of the five duck-population indices and their median seperated for years without hunting (bag limit=0), unrestricted hunting and intermediate bag limit levels. Boxplots depict minimum, 25 percentile, median, 75 percentile and maximum values as well as outliers

Table 4: Overview of the annual bag limits, the five predicted duck population indices, as well as the aggregated point system for the years 1991-2021. Years are ranked by their bag limit.

| | | using water surface | | | using aerial counts | | |
|---|---|---|---|---|---|---|---|
| Year | BagLimit | iPGC | iVicC | iNSWC | tfVicC | tfNSWC | aPS |
| 2007 | 0 | 0.53 | 0.40 | 0.20 | 0.29 | 0.20 | 1 |
| 2008 | 0 | 0.37 | 0.23 | 0.32 | 0.33 | 1.07 | 2 |
| 2003 | 0 | 0.59 | 0.49 | 0.47 | 0.85 | 1.36 | 4 |
| 1995 | 0 | 1.00 | 1.00 | 0.57 | 1.53 | 1.26 | 9 |
| 2004 | 2 | 0.43 | 0.44 | 0.06 | 0.51 | 0.18 | 1 |
| 2009 | 2 | 0.40 | 0.37 | 0.21 | 1.40 | 0.09 | 2 |
| 2020 | 3 | 0.48 | 0.70 | 0.58 | 0.26 | 0.71 | 3 |
| 2016 | 4 | 0.52 | 0.38 | 0.41 | 0.05 | 0.02 | 1 |
| 2015 | 5 | 0.36 | 0.35 | 0.25 | 0.44 | 0.49 | 0 |
| 2019 | 5 | 0.47 | 0.41 | 0.32 | 0.61 | 0.15 | 1 |
| 2010 | 5 | 0.19 | 0.70 | 0.28 | 0.39 | 0.70 | 2 |
| 2005 | 5 | 0.35 | 0.73 | 0.47 | 0.93 | 0.04 | 3 |
| 2000 | 5 | 0.62 | 0.35 | 0.28 | 0.56 | 0.61 | 3 |
| 1998 | 5 | 0.86 | 0.84 | 0.72 | 0.10 | 0.08 | 3 |
| 2021 | 5 | 0.66 | 1.00 | 0.57 | 0.31 | 0.32 | 4 |
| 2001 | 5 | 0.63 | 0.85 | 0.69 | 0.62 | 0.62 | 5 |
| 2002 | 5 | 0.53 | 0.95 | 1.00 | 0.59 | 0.66 | 7 |
| 2006 | 7 | 0.51 | 0.57 | 0.62 | 0.48 | 0.16 | 3 |
| 2014 | 10 | 0.32 | 0.69 | 0.25 | 1.04 | 0.14 | 3 |
| 2018 | 10 | 0.60 | 0.90 | 0.68 | 0.96 | 0.38 | 5 |
| 1997 | 10 | 0.81 | 0.72 | 0.75 | 0.57 | 0.72 | 5 |
| 1999 | 10 | 0.86 | 0.91 | 0.57 | 0.36 | 0.75 | 5 |
| 2017 | 10 | 0.74 | 1.04 | 0.71 | 1.13 | 0.19 | 6 |
| 1996 | 10 | 0.88 | 1.01 | 0.58 | 2.00 | 0.20 | 6 |
| 2011 | 10 | 0.49 | 2.01 | 1.10 | 1.95 | 0.86 | 7 |
| 2013 | 10 | 0.67 | 1.58 | 0.95 | 1.05 | 0.41 | 7 |
| 1993 | 10 | 0.87 | 1.63 | 1.11 | 0.48 | 1.02 | 7 |
| 1994 | 10 | 1.09 | 0.84 | 0.88 | 0.97 | 1.40 | 8 |
| 1992 | 10 | 0.75 | 2.12 | 1.26 | 1.78 | 0.93 | 9 |
| 2012 | 10 | 0.77 | 2.30 | 1.49 | 3.36 | 2.36 | 9 |
| 1991 | 10 | 1.12 | 2.04 | 1.30 | 2.75 | 1.83 | 10 |

Next, in Table 4, the five predicted duck population indices for the years 1991-2021 where years are ranked from most (BagLImit = 0) to least (BagLimit = 10) restricted hunting seasons (values are not considering opening weekend and species-specific regulations). The index values are colour coded with dark colours indicating good and light colours indicating poor population status. White indices relate to proxies from Victoria whereas yellow indices relate to proxies from NSW. In the final column an overall duck-population-valuation is presented using an aggregated point system (*aPS* ) based on all duck population indices in each year. For more detail on the calculation of aPS see section 5.

Finally, in Fig. 12, the actual bag limits and the aggregated point system scores as calculated from the five duck population indices for the years 1991-2021 are plotted against each other. The blue line in this graph depicts the major axis relationship.

The average actual bag limit over the years was 6.2258 and the average aPS was 4.5484. Although tending to be somewhat lower, the aggregated point system does not deviate much from the actual bag limits between 1991 and 2021, with a clear positive relationship between actual bag limits and aggregated point system over this period.

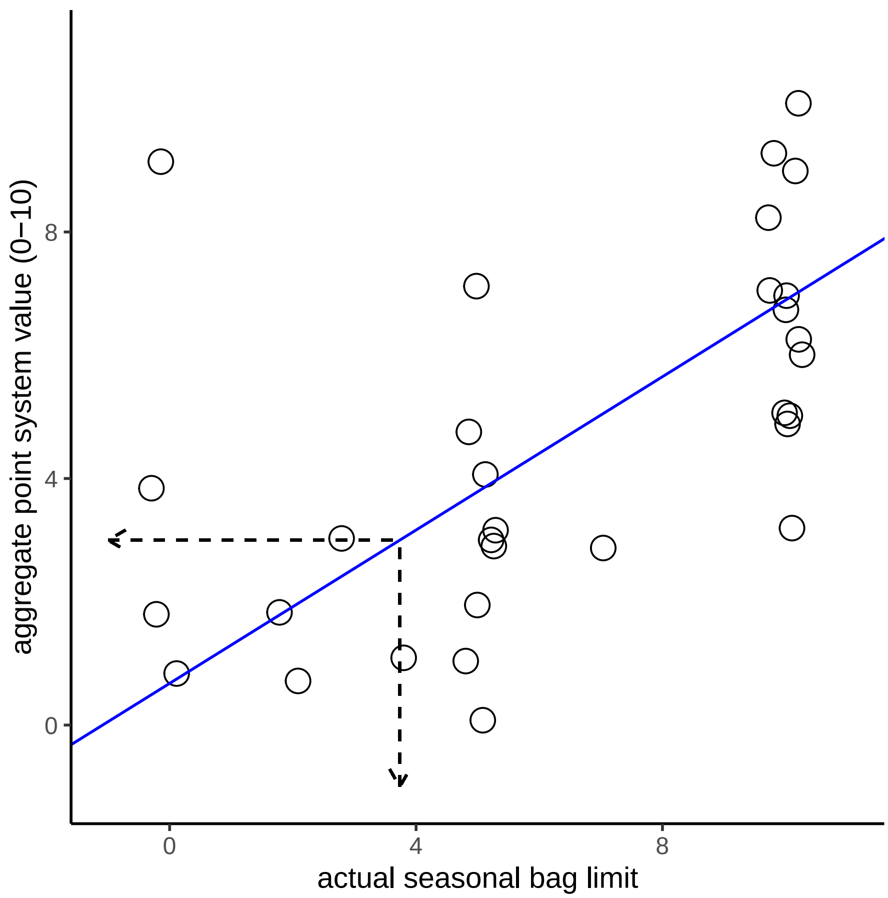


Figure 12: Relationship between the annual bag limit and the aggregated point system value based on the five predicted duck population indices for the years 1991-2021.A small amount of random variation has been added to otherwise overlapping data points to improve data presentation. The blue line is the major axis relationship between the two. Dashed drop lines from this major axis line connects the aPS and proposed bag limit for 2023.

# 5 Proposed hunting arrangement for 2023

Although some indices are less prone to error than others, collective use of these indices should adequately address the four key elements that form part of a decision model. We thus propose to include all five indices in a highly straightforward and transparent manner in guiding decision-making for annual hunting arrangement of which seasonal bag limits form an important part. We propose to do this using the aggregate point system (*aPS*). In this system, each index with a value between 0.5 and 0.9 attracts 1 point and a value over 0.9 attracts 2 points. Given 5 indices, the maximum number of points amounts to 10, when all indices are >0.9. This aggregate point system thus provides a valuation of the overall population status of game ducks in Victoria on a scale from 0-10.

For 2023 the five indices have the following values:

- Using water surface area, the Vic priority game count prediction is: 66259, resulting in an iPGC of: “, 0.86, worth 1 aPS points.
- Using water surface area, the Vic aerial game count prediction is: 35642, resulting in an iVicC of: 0.71, worth 1 aPS points.
- Using water surface area, the NSW aerial game count prediction is: 24517, resulting in an iNSWC of: 0.37, worth 0 aPS points.
- Aerial game counts Vic amounted to: 30557 , and the concomitant tfVicC is: 0.61, worth 1 aPS points.
- Aerial game counts NSW amounted to: 7458 , and the concomitant tfNSWC is: 0.11, worth 0 aPS points.

**Finally, using these five indices in the aggregated Point System calculation results in an aPS of: 3. Using the Major Axis relation between aPS and actual seasonal bag limits (blue line in Fig. 12) this translates to a daily bag limit of 4 ducks per day.**

In light of unprecedented rainfall in recent times this may seem a low limit. It should be reiterated though that this rainfall follows a period of considerable drought and that not all parts of Australia (e.g. LEB) have similarly profited from this rainfall (cf. Fig. 2). Next, it should be reiterated that, based on the modelling results, duck numbers seemingly respond to long-term rainfall patterns (section 4.1). Also, duck counts, both on the ground and from the air, show low to moderate numbers (cf Fig. 3). Finally, it needs stressing that the protocol followed here results in an integration of five indices in a single aPS score that, had it been used in the past, would have performed well in setting bag limits (cf comparisons of aPS scores with actual seasonal bag limits between 1991-2021 in Table 4 and Fig. 12).